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AN INVESTIGATION OF THE THORIUM CONTENT OF MANGANESE NODULES USING NUCLEAR PLATES.

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AN INVESTIGATION OF THE THORIUM CONTENT OF MANGANESE NODULES USING NUCLEAR PLATES.

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INTRODUCTION.

Manganese nodules are occasionally dredged up from the floor of the oceans, and consist chiefly of manganese dioxide and ferric oxide. The question of the origin of the nodules is discussed by H. Pettersson (1) ; the iron and manganese may be of volcanic origin, or may be precipitated from the sea water. The nodules are usually formed in concentric layers round a piece of pumice or a shark's tooth, and are assumed to have grown round this nucleus.

H. Pettersson (2) has measured the radium content of nodules by the emanation method. He found an increase in radium content in passing from the centre to the surface of the nodule, and assuming this to be due to the decay of unsupported radium, calculated the rate of growth of the nodule to be about 1 mm. in 1,000 years. The nodules may also contain unsupported ionium ; Piggot and Urry (3) explained the distribution of radium in some sediment cores by assuming the presence of unsupported ionium.

F. Koczy (4) has measured the thorium content of a nodule and of a few samples of red clay and globigerina ooze using the emanation method. His results were $0{\cdot}5 - 0{\cdot}9 \times 10^{-7}$ g.Th/g. for red clay, $1{\cdot}1 - 1{\cdot}5 \times 10^{-7}$ g.Th./g. for globigerina, and $1{\cdot}3 \times 10^{-6}$ g.Th/g. for the nodule. He points out that owing to precipitation of thorium as fluoride on entering the sea, near shore sediments should have a higher thorium content than deep sea sediments, and his results show this effect. The thorium content of sea water is very low ; E. Föyn and E. Rona (5) give $0{\cdot}5 \times 10^{-9}$ g.Th./c.c. as an upper limit. H. Pettersson (2) put forward the hypothesis that thorium (and hence its isotope ionium) is precipitated from sea water together with ferric hydroxide. This would explain the fact that the radium content of sea water is less than that required for equilibrium with the uranium present, since ionium is the parent of radium. If the nodules are derived from iron and manganese from the sea water they should thus contain very little thorium, but if they are of volcanic origin their thorium content need not necessarily be low. The mean thorium content of continental rocks is about $1{\cdot}5 \times 10^{-5}$ g.Th/g., and that of volcanic lavas $2{\cdot}3 \times 10^{-5}$ g.Th./g.

H. Buttlar and F. Houtermanns (6) exposed nuclear plates to a nodule to record the alpha ray emission. They found that the emission increased with increasing distance from the centre of the nodule, with a particularly high emission from a small outgrowth, and from a hemispherical hole near the centre of the nodule. They calculated that the rate of growth was 0·6 mm. in 1,000 years. They surrounded the nodule with a plastic, ' palladon,' before cutting it in half, in order to prevent it from crumbling. It is not made clear whether the nodule was impregnated with plastic or merely coated with plastic on the outside. The possibility that radon and thoron diffuse out of the nodule must be considered, and the application of the plastic would probably decrease the emanating power. The highest emission obtained by Buttlar and Houtermanns was 110 alpha particles/mm^2 in 17 days, or 27 alpha particles/cm^2/hour, corresponding to 80×10^{-12} gm. radium/gm.

Experimental Results.

The nuclear plates used were Ilford C.2 type, emulsion thickness 50μ, and recorded the alpha ray emission. They were processed according to the maker's instructions using Ilford I.D. 19 developer. The alpha ray tracks in the emulsion were examined with a Bausch and Lomb microscope and micrometer eyepiece, with a 4 mm. dry objective. A correction must be applied to the total emission for the background count due to radioactive impurities in the glass backing of the plate. Only the horizontal projections of the tracks were measured, as this is much less laborious and uncertain than the previous method of measuring also the vertical dip and then calculating the actual track length. The theory given by J. H. J. Poole and C. M. E. Matthews (7) was used, the results of which are as follows.

A thin source is defined as a plane surface distribution of uniformly radioactive material of negligible thickness compared to the range of the shortest alpha ray concerned; and a thick source as a plane distribution of uniformly radioactive material of thickness greater than the longest alpha ray concerned.

Considering first a single alpha ray emitter we found that for a thin source

$$P = 100 \sqrt{1 - a^2}$$

where P = percentage of tracks whose horizontal range in air exceeds aR, where R is the maximum range of the alpha ray in air and a is a proper fraction. The results for the distribution of ranges will be the same in the emulsion as in air.

For a thick source we considered an alpha particle emitted at a depth x below the horizontal surface of the source, whose track makes an angle θ with the vertical. We showed that the maximum horizontal range in air will only exceed aR for values of θ between the limits θ_1 and θ_2 which are functions of x and that

$$P = 200 \int_0^K (\text{Cos } \theta_1 - \text{Cos } \theta_2)\, dk$$

$k = x/R\mu$ where μ = ratio of range in source to range in air.

$$K = (\text{Cos Sin}^{-1} \sqrt[3]{a})^3$$

The integral is evaluated by approximate methods.

For a family of elements the number of tracks which exceed a given range is found by summation for the different elements concerned. A correction must be applied for the minimum visible range as tracks whose horizontal length in the emulsion is equivalent to less than 8 mm. in air were found to be too short to be counted.

Let p_1 = total number of alpha ray tracks on the plate/cm²/sec. of exposure,
p_2 = number of these alpha rays/cm²/sec. whose horizontal length exceeds the range of RaC'

The longest alpha ray ranges are those of RaC', 6·91 cm., in the uranium series, and of ThC', 8·57 cm., in the thorium series. Therefore the tracks whose lengths exceed the range of RaC' must be due to ThC'.

Since there are six alpha rays in the thorium series, allowing for the minimum visible range we find that for a thin source of thorium

$$p_1 = 5{\cdot}88\ N_{Th}\ W_{Th} / 2$$

where N_{Th} = number of alpha particles emitted / sec. / g. of Th232.
and W_{Th} = surface concentration of Th232 in g./cm.².

Also $p_2 = 0{\cdot}38\ N_{Th}\ W_{Th} / 2$

$$\therefore\ p_1/p_2 = 15{\cdot}5$$

Similarly for a thin source of thoron $p_1 = 2{\cdot}96\ N_{Th}\ W_{Th} / 2$.

Considering a thick source of thorium we find that

$p_1 = \frac{1}{4}\mu d.\ 19{\cdot}5\ N_{Th}\ C_{Th}$ and $p_2 = \frac{1}{4}\ \mu d.\ 0{\cdot}20\ N_{Th}\ C_{Th}$, where d is density of source,

and C_{Th} = Thorium content of source in g. / g.

$$\therefore\ p_1 / p_2 = 97$$

∴ For a thick source containing Th232, $p_1 / p_2 < 97$. For a fuller description of these calculations, reference may be made to the paper mentioned above (7).

Nodule surfaces.—Seven nodules from the Atlantic Ocean, one nodule from the Pacific Ocean, and a large manganese crust were investigated. The nodules had been cut in half, and plates were exposed by placing them on top of the nodule in contact with the cross sectional surface in a light-tight box.

It was found that in general there was no increase in track density in passing from the centre to the edge of the nodule, but that there was a large increase in track density on the part of the plate which projected over the edge of the nodule and was not in contact with the surface. There was also a smaller increase over a large area above a shallow indentation in the nodule surface. This is to be expected, since it is only the surface layer of the nodule which is effective in emitting alpha particles,

and where the surface is rough and indented, a given area of the plate will be exposed to a greater area of nodule surface ; however, the effect was rather large to be accounted for in this way.

The total horizontal range distribution was found for two nodules, and is shown in Fig. 1 and Table 1. The distributions for thin and thick sources of thorium are also given for comparison. The distribution for the nodule lies much nearer to that for a thin source than to that for a thick source. The nodule certainly does not behave as a thick source.

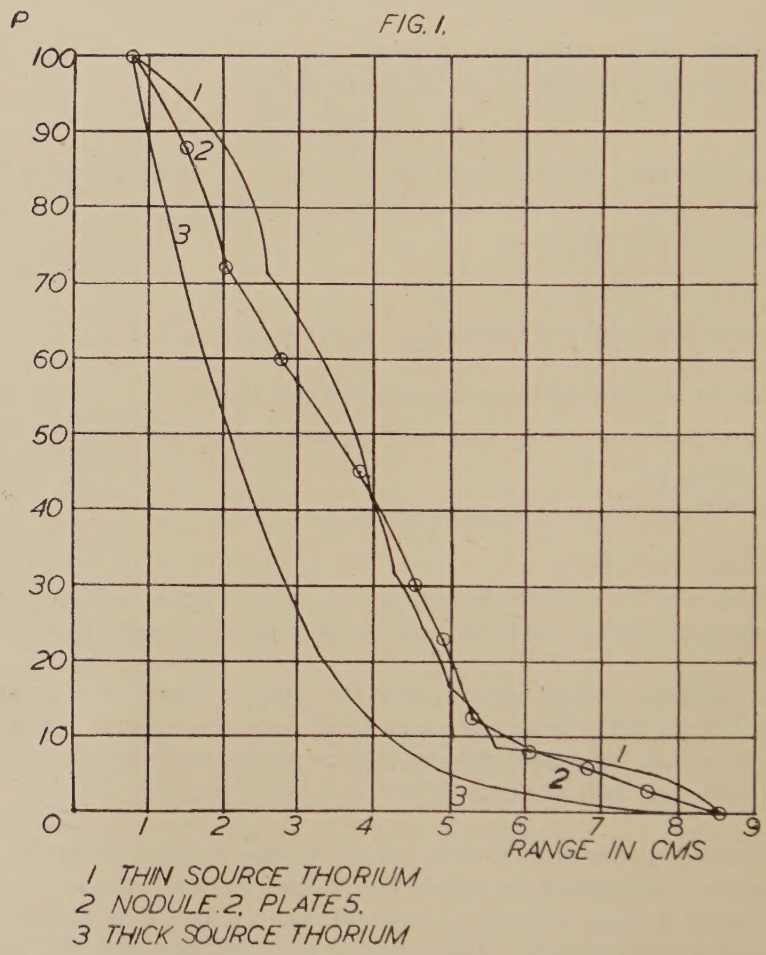


TABLE 1.

Range in cm. of air	Plate 1 Nodule 1	Plate 5 Nodule 2	Thin source of thorium	Thick source of thorium
	P	*P*	*P*	*P*
0·80	100	100	100	100
1·52	94	88	93·8	70·0
2·28	84	72	83·4	47·0
3·03	70	60	65·0	25·1
3·80	56	45	49·0	13·8
4·56	33	30	26·9	7·3
4·94	22	23	19·2	5·5
5·32	15	13	13·2	4·3
6·08	8	7	8·0	2·2
6·85	6	6	6·8	1·2
7·60	3	3	5·2	0·6
8·57	0	0	0	0

The average number of alpha ray tracks/cm²/hour on the plate is given in Table 2, and varies for the different nodules; in general it is of the same order of magnitude as the result obtained by Buttlar and Houtermanns (6). Table 2 also shows the number of tracks/cm²/hr. which exceed in horizontal length the range of RaC', and the ratio of p_1/p_2.

The values of p_1/p_2 show that there are too many long tracks for a thick source. The large number of long tracks cannot be due to the emission from thorium impurities in the glass backing of the plate, as it was found that this emission was negligible.

TABLE 2.

Nodule No. 4 from Pacific Ocean (37°52'N, 160°17'W, 2740 fms.). Other nodules from Atlantic Ocean

p_1 = total number of tracks on the plate/cm²/sec.

p_2 = no. of these/cm²/sec whose horizontal length exceeds range of RaC'

$p_1/p_2 < 97$ for thick source.

Plate No.	Source		No. of alpha ray tracks /cm²/hr. on the plate	No. of tracks /cm²/hr. exceeding in horizontal length the range of RaC'	p_1/p_2
1	Nodule 1	Surface 1	59·5	3·56	16·7
2		Surface 2	39·2	1·85	21·1
3		Surface 3	60·0	3·38	17·7
4	Nodule 2	Surface 1	31·4	1·13	27·8
5		Surface 2	20·4	0·90	22·6
6		Surface 3	18·9	0·93	20·4
7	Nodule 4	Surface 1	45·5	3·22	14·1
8		Surface 2	50·8	2·28	22·2
9	Nodule 5		2·4	—	—
10	Nodule 6	Position 1	9·2	0·23	39·7
11		Position 2	8·1	0·20	41·5
12	Nodule 7		8·1	0·27	30·3
13	Manganese Crust				
		Position 1	24·5	1·69	14·5
14		Position 2	31·2	1·93	16·2
15		Position 3	29·5	1·65	17·9
16	Newry Granite		3·8	0·13	28·4

A piece of granite behaved in the same way as the nodules (Table 2), and did not act as a thick source. Since the granite was quite smooth the effect cannot be entirely due to the roughness of the nodule surfaces.

Powdered nodules.—Plates were also exposed to powder filed off the cross sectional surfaces of the nodules. It was found that the total emission in each case was very much less than for the nodule surface, and also that the proportion of long tracks was diminished. The results are given in Table 3, sources (*a*).

To determine whether the emission depended on particle size, an attempt was made to grind the powder in an agate mortar. Owing to the sticky nature of the powder this was difficult, and no appreciable decrease in particle size could be observed under the microscope. The powder used for sources (*a*) was then shaken in a fine linen sieve and plates exposed to the powder which passed through the sieve (*b*), and also to the powder which would not pass through the sieve (*c*). The results are shown in Table 3. There is no definite effect on the total emission ; for nodules 1 and 2 the total emission is low and the method is not accurate enough to measure small changes. The proportion of long tracks is decreased both for (*b*) and (*c*). For sources (*b*) and (*c*) the quantity of powder used and the thickness of the powder layer was less than for (*a*). It appears therefore that the decrease in the proportion of long tracks for (*b*) and (*c*) is due to the smaller quantity of powder used, and not to the effect of sieving, since there is no significant difference between (*b*) and (*c*).

TABLE 3.

Plate No.	SOURCE	No. of alpha ray tracks /cm²/hr.	No. of tracks /cm²/hr. exceeding in horizontal length the range of RaC'	p_1/p_2
	NODULE 1			
17	(*a*) Powder	8·99	·0710	126
18	(*b*) Powder passed through sieve	5·93	·0104	571
19	(*c*) Powder left in sieve ...	8·18	·0173	471
	NODULE 2			
20	(*a*) Powder	8·49	·0555	153
21	(*b*) Powder passed through sieve	9·54	·0173	553
22	(*c*) Powder left in sieve ...	10·0	·0167	599
	NODULE 3			
23	(*a*) Powder	23·7	·128	185
24	(*b*) Powder passed through sieve	14·7	·0257	571
25	(*c*) Powder left in sieve ...	10·0	·0351	285
	NODULE 4			
26	(*a*) Powder	5·4	—	—

p_2=No. of tracks/cm²/sec. whose horizontal length exceeds the range of RaC'.
p_1=total No. of tracks on the plate/cm²/sec.

Escape of emanation from powdered nodules.—The following experiments prove that the emanation escapes from the powdered nodules. A weighed quantity of powder was placed in a steel box whose total volume was about 32 c.c. The plate was supported above the powder with the emulsion side upwards, so that no alpha ray coming directly from the powder could enter the emulsion. The emanation, however, could diffuse round to the emulsion side of the plate. The lid of the box was screwed down tightly by means of four screws, and the joint was also sealed with plasticine on the outside. A plate exposed in the empty steel box as a blank recorded an emission of 4·22 alpha particles/cm.^{2}/hour. The corrected results for the powdered nodules are shown in Table 4. This remaining emission must be due to emanation which has diffused out of the powder.

TABLE 4

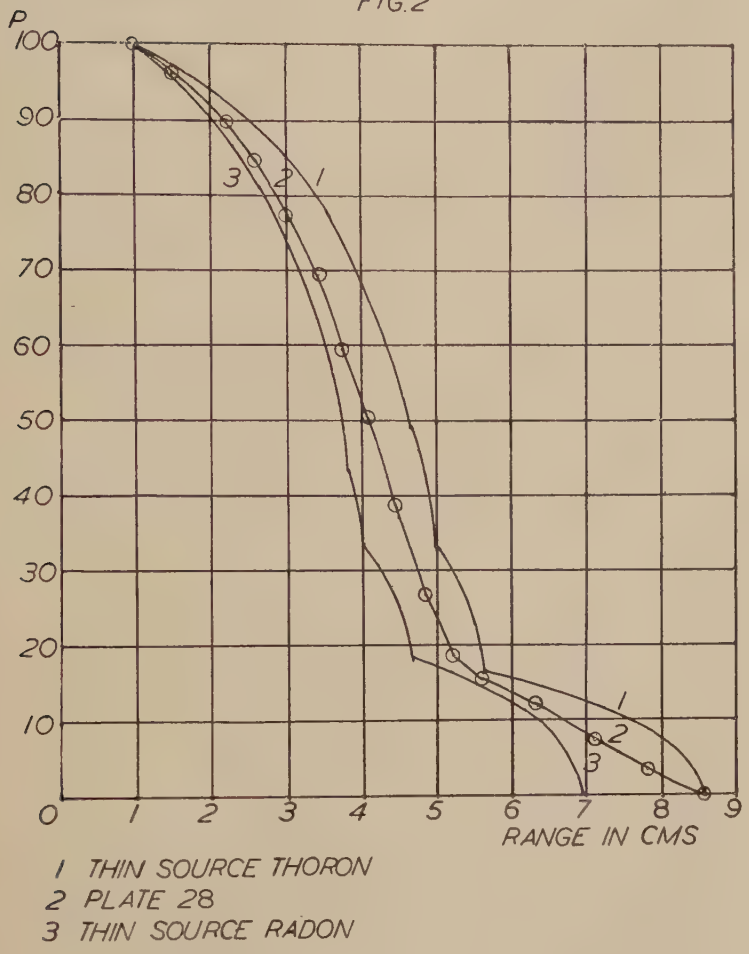
Plates exposed in sealed box with emulsion side upwards for plates 27–31 and with emulsion side downwards for plate 32.

Plate No.	Source	Exposed in	Mass of powder g.	Mass/area of powder g./cm.^{2}	p_2	Minimum C_{Th}
27	Nodule 1	Steel box	0·550	0·031	$1·68 \times 10^{-4}$	$3·85 \times 10^{-5}$
28	Nodule 3	Steel box	2·850	0·161	$6·59 \times 10^{-4}$	$2·85 \times 10^{-5}$
29	Nodule 4	Steel box	1·612	0·091	$5·24 \times 10^{-4}$	$3·82 \times 10^{-5}$
30	Nodule 4	Steel box	0·589	0·033	$1·77 \times 10^{-4}$	$3·90 \times 10^{-5}$
31	Nodule 4	Brass box	0·267	0·033	$4·32 \times 10^{-4}$	$3·70 \times 10^{-5}$
32	Nodule 4	Brass box emulsion downwards	0·267	0·033	$1·33 \times 10^{-4}$	—

The distance from the emulsion to the lid of the steel box was 0·34 cm. The range of the shortest alpha ray concerned was 2·60 cm., so that the layer of emanation to which the plate was exposed approximated to a thin source. The total horizontal range distribution for plate 28, exposed to powdered nodule 3 in the steel box, is shown in Fig. 2, the distribution lies between that for a thin source of thoron and that for a thin source of radon. These results indicate that both thoron and radon escape from the powder.

A brass box was also used in the same way as the steel box. The volume of the brass box was about 3·5 c.c., and it was sealed with 'cellotape' instead of with plasticine. A blank experiment was also carried out for the brass box, and the number of tracks on the plate was found to be 14·1/cm^2/hour. The results were corrected for this emission. This blank emission for the brass is remarkably high; for example, it corresponds to a thick source of uranium containing $4·3 \times 10^{-5}$ g.U/g.

FIG.2



Minimum thorium content.—In Table 4 the minimum thorium content is given. In order to calculate this it is assumed that the mass of emanation escaping from the powder depends only on the mass of powder present and not on the thickness of the layer of powder; and also that the time taken by the emanation to diffuse round to the emulsion side of the plate is negligible compared with the half life of the emanation, so that the emanation is uniformly distributed inside the box. The experimental results are in accordance with these assumptions. If the assumptions are not correct, the total emission/hr./g. deduced below will be too small, so that the thorium content obtained will still be a minimum value.

It is also assumed that the escaping thoron is in equilibrium with its products. The longest half life concerned is that of ThB, 10·6 hours, and since the exposure time was of the order of three to four weeks, the time required for equilibrium to be established is negligible.

Let A = area of plate

V = volume of air in box

t = thickness of layer of emanation to which plate is exposed, i.e., distance from emulsion to lid of box

m = mass of powder

N_{Th} = No. of alpha particles emitted by Th.232 per sec. per g. of Th.232 $= 4 \times 10^3$

C_{Th} = thorium content of source in g./g.

Q = fraction of total thoron formed which escapes from powder into air space in box = emanating power for thoron

p_2 = number of tracks/cm²/sec whose horizontal length exceeds the range of RaC'.

Total No. of alpha particles emitted/sec by Th.232 in powder

$= m C_{Th} N_{Th}$

= total No. of alpha particles emitted/sec by the thoron in equilibrium with the Th.232.

$\therefore$ No. of alpha particles emitted/sec by thoron which escapes from powder $= Q\, m\, C_{Th} N_{Th}$.

Fraction of the thoron which escapes from the powder which gives rise to tracks on the plate $= At/V$.

$\therefore$ No. of tracks/sec on plate due to thoron $= Q\, m\, C_{Th}\, N_{Th}\, At/2V$.

$\therefore$ No. of tracks/cm²/sec on plate due to ThC' $= 0.65\, Q\, m\, C_{Th}\, N_{Th}/2V$.

Since ThC' is formed in 65 per cent. of the disintegrations of ThC. No. of these tracks/cm²/sec whose horizontal length exceeds the range of RaC' $= \sqrt{1-a^2} \times 0{\cdot}65\, Q\, m C_{Th}\, N_{Th}\, t/2V$ where $a = 6{\cdot}81/8{\cdot}57$

$= 0{\cdot}19\, Q\, m\, C_{Th}\, N_{Th}\, t/V = p_2$

$\therefore\ C_{Th} = p_2 V/0{\cdot}19\, Q\, m\, N_{Th}\, t$

Now $N_{Th} = 4 \times 10^3$ Maximum $Q = 1$

$\therefore$ Minimum $C_{Th} = 1{\cdot}32 \times 10^{-3}\, p_2\, V/m\, t$

The minimum thorium contents are given in Table 4, and are fairly constant.

Maximum thorium content.—A maximum thorium content can be found for nodule 4 from the results for Plates 31 and 32 (see Table 4). Plate 31 was exposed to powdered nodule 4 in the brass box with the emulsion side upwards. Plate 32

was exposed to the same powder with the emulsion side downwards, so that this plate also recorded the alpha rays coming directly from the powder, which acts as a thick source.

$\therefore$ for plate 32, $p_2 = b + c$.

Where b = No. of tracks/cm²/sec on plate whose horizontal length exceeds the range of RaC' due to the thin source of thoron.

c = No. of tracks/cm²/sec on plate whose horizontal length exceeds the range of RaC' due to the thick source.

p_2 = total No. of tracks/cm²/sec. on plate whose horizontal length exceeds the range of RaC'.

The results for Plates 31 and 32 are:

Plate	p_2	m	t	V
31	$4{\cdot}32 \times 10^{-4} \pm 10\%$	0·267	0·166	2·76
32	$1{\cdot}33 \times 10^{-4} \pm 10\%$	0·267	0·048	2·85

b can be calculated for plate 32 from the results for plate 31, allowing for the difference in the thickness of the source of thoron to which the plate is exposed and the difference in the total volume of thoron.

$$\text{Thus } b = 4{\cdot}32 \times 10^{-4} \times \frac{0{\cdot}048}{0{\cdot}166} \times \frac{2{\cdot}76}{2{\cdot}85}$$

$\therefore b = 1{\cdot}20 \times 10^{-4} \pm 10\%$.

For plate 32. $p_2 = 1{\cdot}33 \times 10^{-4} \pm 10\% = 1{\cdot}20 \times 10^{-4} \pm 10\% + c$

$\therefore c = (1{\cdot}33 \times 10^{-4} \pm 10\%)$—$(1{\cdot}20 \times 10^{-4} \pm 10\%)$

$\therefore$ Maximum value for $c = 3{\cdot}8 \times 10^{-5}$.

For a thick source containing thorium, the number of tracks/cm²/sec. on the plate whose horizontal length exceeds the range of RaC' = 0·20 μd N_{Th} $C_{Th}/4$. μd can be calculated from the Bragg-Kleeman rule (8), and the result is not very sensitive to the exact chemical composition.

μd for $MnO_2 = 1{\cdot}65 \times 10^{-3}$ μd for $Fe_2O_3 = 1{\cdot}92 \times 10^{-3}$

$\therefore$ μd for nodules $\sim 1{\cdot}8 \times 10^{-3}$. $N_{Th} = 4 \times 10^3$.

$\therefore$ 0·20 μd N_{Th} $C_{Th}/4 = 0{\cdot}36\ C_{Th}$.

$\therefore$ For plate 32 $c = 0{\cdot}36\ C_{Th}\ (1-Q)$.

$\therefore$ $0{\cdot}36\ C_{Th}\ (1-Q) < 3{\cdot}8 \times 10^{-5}$.

$Q\ C_{Th} = 3{\cdot}7 \times 10^{-5}$. (See Table 4).

$\therefore$ $C_{Th} < 1{\cdot}43 \times 10^{-4}$.

$\therefore$ For nodule 4 the thorium content is less than $14{\cdot}3 \times 10^{-5}$ g./g. and greater than $3{\cdot}7 \times 10^{-5}$ g./g.

An attempt was made to measure the emission which came directly from the powder as well as the emission due to the emanation by exposing plates emulsion side downwards above the powder in another type of sealed apparatus. The plate was clamped between rubber rings, and formed the lid of a small brass container which held the powder. However, it was found that an error was introduced, since in this apparatus the air space inside the pores of the powder was not negligible compared with the air space above the powder. Therefore some of the emanation which diffused out of the solid remained inside the pores of the powder and gave rise to alpha rays which were not recorded on the plate. In this type of experiment it is therefore necessary to ensure that the air space above the powder is sufficiently large.

If the powder could be compressed so that there were no air spaces, and the plate exposed in close contact with it in a sealed apparatus, it should act as a thick source, as there would be no space into which the emanation could escape. However, if the powder is compressed, it sticks to the emulsion and cannot be washed off, also pressure on the emulsion causes blackening of the plate, and so this is not practicable.

Discussion of Results.

The experimental results for the nodule surfaces and the powdered nodules can now be explained. Since the emanation escapes from the powder it is very probable that it escapes from the nodule surfaces also. The emanating power for thoron of manganese dioxide is 5% at room temperature. The emanating power for thoron of ferric oxide which has been strongly ignited is 1% (9, 10), and that of ferric oxide which has been heated to 300°C is 50% (9). The nodules and the powder were not heated, and so their emanating powers are probably high.

The range distribution for the nodule surfaces could be explained by assuming that the thorium is concentrated round the outside of the particles of the nodule, so that the plate is exposed to a thin source of thorium. This surface emission should also be recorded when a plate is exposed to the powdered nodule, but the emission from the powder was much smaller than from the nodule surface. Therefore, not more than a small fraction of the total emission from the nodule surface can be due to a thin source of thorium.

The high proportion of long tracks can therefore only be explained by assuming that most of the emission from the nodule surface is due to the emanation. A small part of the emission is probably due to the thick source layer at the surface of the nodule, so that the total range distribution does not quite coincide with that for a thin source containing thoron and radon, but lies between the latter distribution and that for a thick source. The emission from the thick source layer will not necessarily be the same for the powder, as the emanating power of the powder may not be the same as for the nodule surface.

The mass of powder used for the sources was of the order of 50 milligrams, whereas the mass of the nodules was of the order of a thousand times greater. The total quantity of emanation produced per second by the nodule was thus about a thousand times greater than that produced per second by the powder. This factor will tend to make the emission from the powder smaller than the emission from the nodule surface. The emanation may diffuse out of the powder more or less rapidly than out of the nodule. It will probably diffuse right out into the surrounding air more rapidly in the case of the powder, where there are no large holes in which the emanation can collect (as in the nodule surface); also owing to the volume of powder being much smaller than that of the nodule, the emanation can escape more easily. The lower emission in the case of the powdered nodule is therefore understandable. Since the decrease in the total emission is due to a decrease in the emission due to the emanation, the proportion of long tracks will also be smaller for the powder—as was observed. Some of the emission from the powdered source is still due to the emanation, since the emission depends on the mass of powder used for the source.

The number of tracks per cm.^{2} on the plates exposed to the nodule surfaces will depend on the thickness of the layer of emanation to which the plate is exposed, so that there will be a greater track density over holes and indentations in the nodule surfaces, as was observed. The part of the plate which projects over the edge of the nodule so that it is not in contact with the nodule surface will be exposed to the thickest layer of emanation, and so the track density will be greatest for this part of the plate. Although the emanation is diffusing away to the surrounding air, it is being continuously replaced from inside the nodule, and some of it will disintegrate at the surface.

The emission due to thoron will mask the effect of the concentration of radium in the outermost layers of the nodule. Also the emanation which disintegrates below a given area of the plate will not necessarily have come from the part of the nodule which is immediately below the plate.

These results show that the nuclear plate method, which is useful on account of its high sensitivity, must be used with caution. Unless the substance used as a source has a very low emanating power for thoron and radon, the method of simply exposing the plate in contact with the surface cannot be used. A minimum value for the thorium content can be obtained by the method described above, which is very sensitive if the emanating power is fairly high. This experiment should always be carried out as a preliminary; the approximate thorium content is usually known so that the approximate emanating power can then be found.

In conclusion I should like to express my thanks to Professor J. H. J. Poole for all his help. My thanks are also due to Professor H. A. Pettersson for his help and for the loan of the manganese nodules; also to the British Museum for one of the nodules.

Summary.

Experiments are described which indicate that the emanating power of manganese nodules is fairly high. The results of exposing nuclear plates to the nodules are discussed and can probably be explained in terms of this high emanating power.

The minimum thorium content of the nodules is determined by a new method, with the following results :

	Minimum thorium content	Maximum thorium content
Nodule 1	$3{\cdot}85\times10^{-5}$	—
Nodule 3	$2{\cdot}85\times10^{-5}$	—
Nodule 4	$3{\cdot}81\times10^{-5}$	$14{\cdot}3\times10^{-5}$

The nodules therefore contain considerably more thorium than was previously supposed, the content being comparable with that of an average acid igneous rock.

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